Reproductive System Module 1: Introduction
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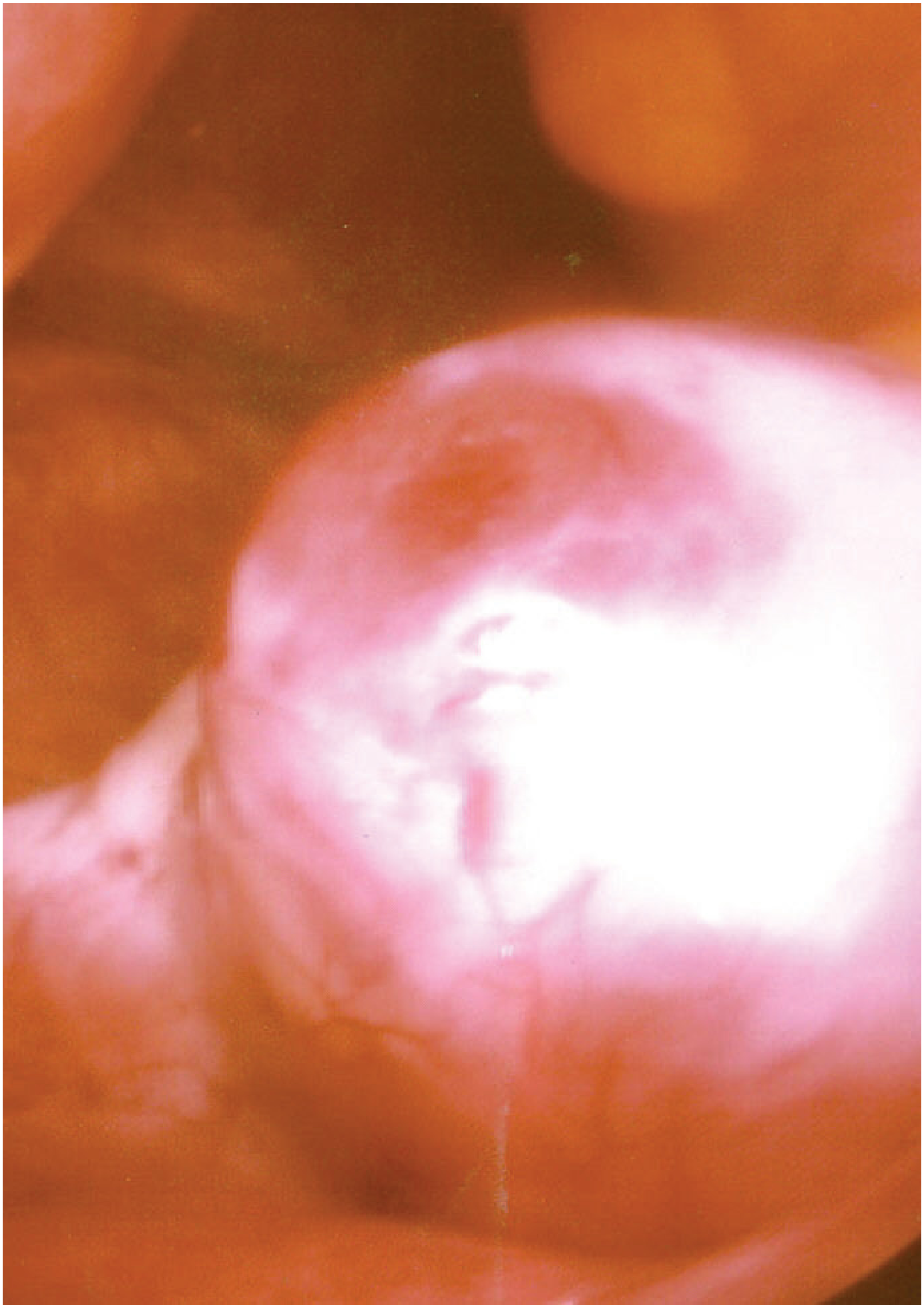
Ovulation

Following a surge of luteinizing hormone (LH), an oocyte (immature egg cell) will be released into the uterine tube, where it will then be available to be fertilized by a male’s sperm. Ovulation marks the end of the follicular phase of the ovarian cycle and the start of the

luteal
phase.



Note:
Chapter Objectives
After studying this chapter, you will be able to:

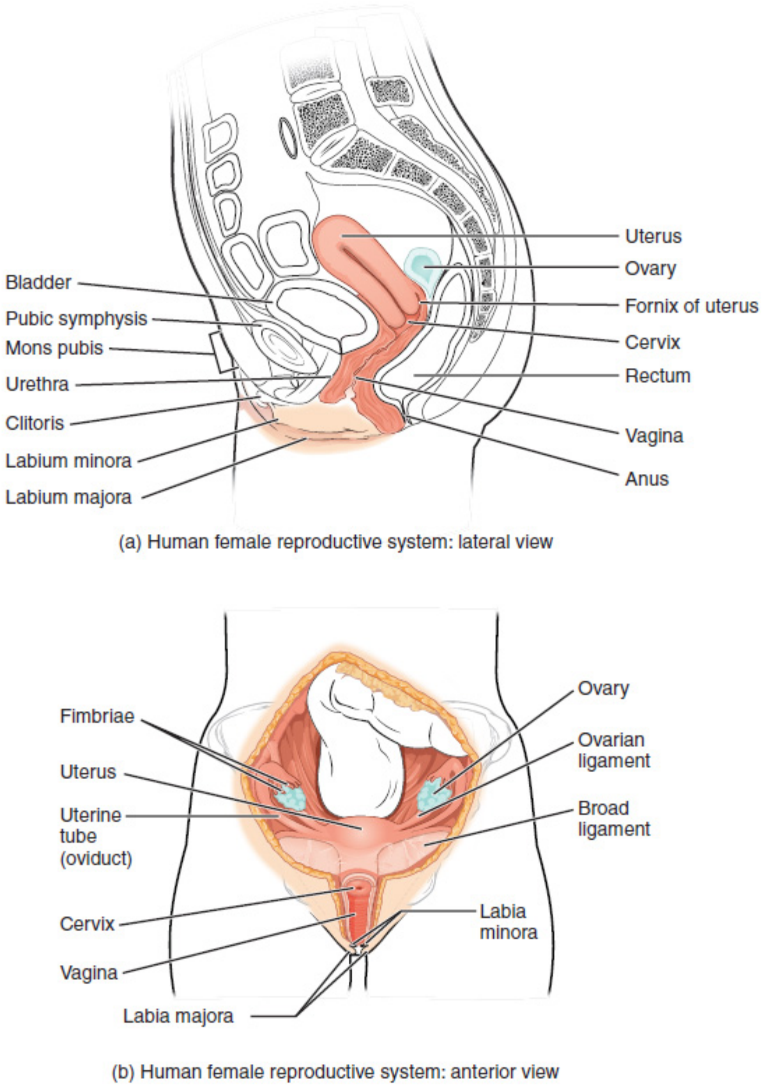
- Describe the anatomy of the male and female reproductive systems, including their accessory structures
- Explain the role of hormones in male and female reproductive function
- Trace the path of a sperm cell from its initial production through fertilization of an oocyte
- Explain the events in the ovary prior to ovulation
- Describe the development and maturation of the sex organs and the emergence of secondary sex characteristics during puberty

Small, uncoordinated, and slick with amniotic fluid, a newborn encounters the world outside of her mother’s womb. We do not often consider that a child’s birth is proof of the healthy functioning of both her mother’s and father’s reproductive systems. Moreover, her parents’ endocrine systems had to secrete the appropriate regulating hormones to induce the production and release of unique male and female gametes, reproductive cells containing the parents’ genetic material (one set of 23 chromosomes). Her parent’s reproductive behavior had to facilitate the transfer of male gametes—the sperm—to the female reproductive tract at just the right time to encounter the female gamete, an oocyte (egg). Finally, combination of the gametes (fertilization) had to occur, followed by implantation and development. In this chapter, you will explore the male and female reproductive systems, whose healthy functioning can culminate in the powerful sound of a newborn’s first cry.

Module 2 Anatomy and Physiology of the Female Reproductive System
By the end of this section, you will be able to:

- Describe the structure and function of the organs of the female reproductive system
- List the steps of oogenesis
- Describe the hormonal changes that occur during the ovarian and menstrual cycles
- Trace the path of an oocyte from ovary to fertilization

Reproductive System Module 2: The Female Reproductive System
The female reproductive system functions to produce gametes and reproductive hormones, just like the male reproductive system; however, it also has the additional task of supporting the developing fetus and delivering it to the outside world. Unlike its male counterpart, the female reproductive system is located primarily inside the pelvic cavity ([link]). Recall that the ovaries are the female gonads. The gamete they produce is called an **oocyte**. We’ll discuss the production of oocytes in detail shortly. First, let’s look at some of the structures of the female reproductive system.
Female Reproductive System



The major organs of the female reproductive system are located inside the pelvic cavity.

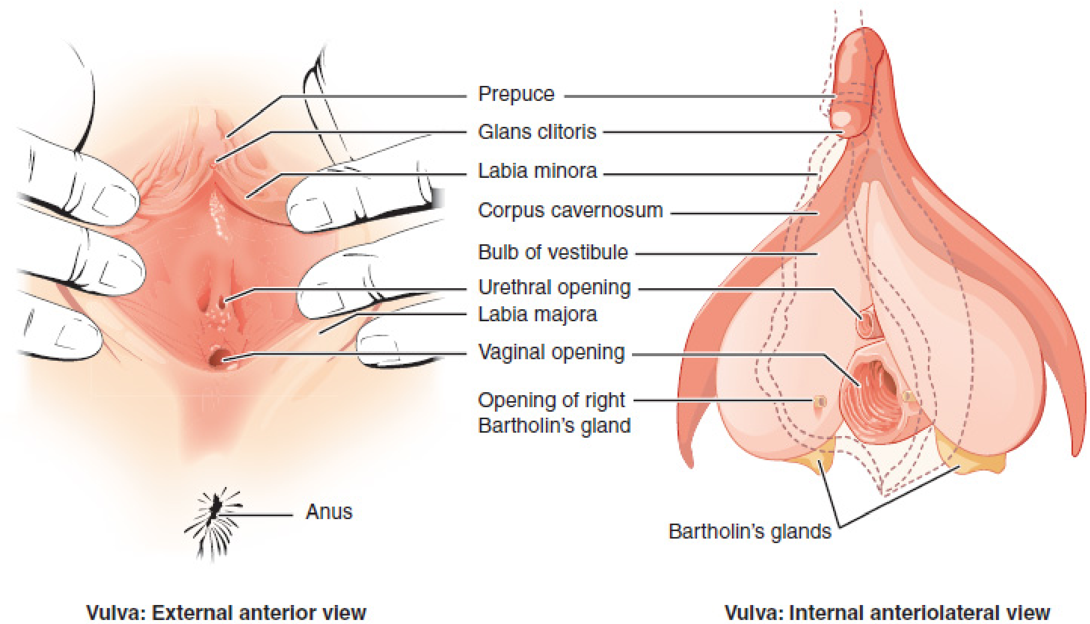
External Female Genitals

The external female reproductive structures are referred to collectively as the **vulva** ([link]). The **mons pubis** is a pad of fat that is located at the anterior, over the pubic bone. After puberty, it becomes covered in pubic hair. The **labia majora** (labia = “lips”; majora = “larger”) are folds of hair-

covered skin that begin just posterior to the mons pubis. The thinner **labia minora** (labia = “lips”; minora = “smaller”) are between the the labia majora. The labia minora serve to protect the female urethra and the entrance to the female reproductive tract.

The **clitoris** (or glans clitoris) is an organ that originates from the same cells as the glans penis and has abundant nerves that make it important in sexual sensation and orgasm. The **hymen** is a thin membrane that sometimes partially covers the entrance to the vagina. An intact hymen cannot be used as an indication of “virginity”; even at birth, this is only a partial membrane, as menstrual fluid and other secretions must be able to exit the body, regardless of penile–vaginal intercourse. The vaginal opening is located between the opening of the urethra and the anus. It is flanked by outlets to the **Bartholin’s glands** (or greater vestibular glands).

The Vulva



The external female genitalia are referred to collectively as the vulva.

Vagina

The **vagina**, shown at the bottom of [link] and [link], is a muscular canal (approximately 10 cm long) that serves as the entrance to the reproductive tract. It also serves as the exit from the uterus during menses and childbirth. The thin, perforated hymen can partially surround the opening to the vaginal orifice. The hymen can be ruptured with strenuous physical exercise, penile–vaginal intercourse, and childbirth. The **Bartholin’s glands** and the lesser vestibular glands (located near the clitoris) secrete mucus, which keeps the vestibular area moist.

Ovaries

The **ovaries** are the female gonads (see [link]). Paired ovals, they are each about 2 to 3 cm in length, about the size of an almond. The ovaries are located within the pelvic cavity, and are supported by the **mesovarium**, an extension of the peritoneum that connects the ovaries to the **broad ligament**. Extending from the mesovarium itself is the **suspensory ligament** that contains the ovarian blood and lymph vessels. Finally, the ovary itself is attached to the uterus via the **ovarian ligament**.

The ovary comprises an outer covering called the tunica albuginea. Beneath the tunica albuginea is the cortex, or outer portion, of the organ. The ovarian stroma forms the bulk of the adult ovary. Oocytes develop within the outer layer of this stroma, each surrounded by supporting cells. This grouping of an oocyte and its supporting cells is called a **follicle**.

The Ovarian Cycle

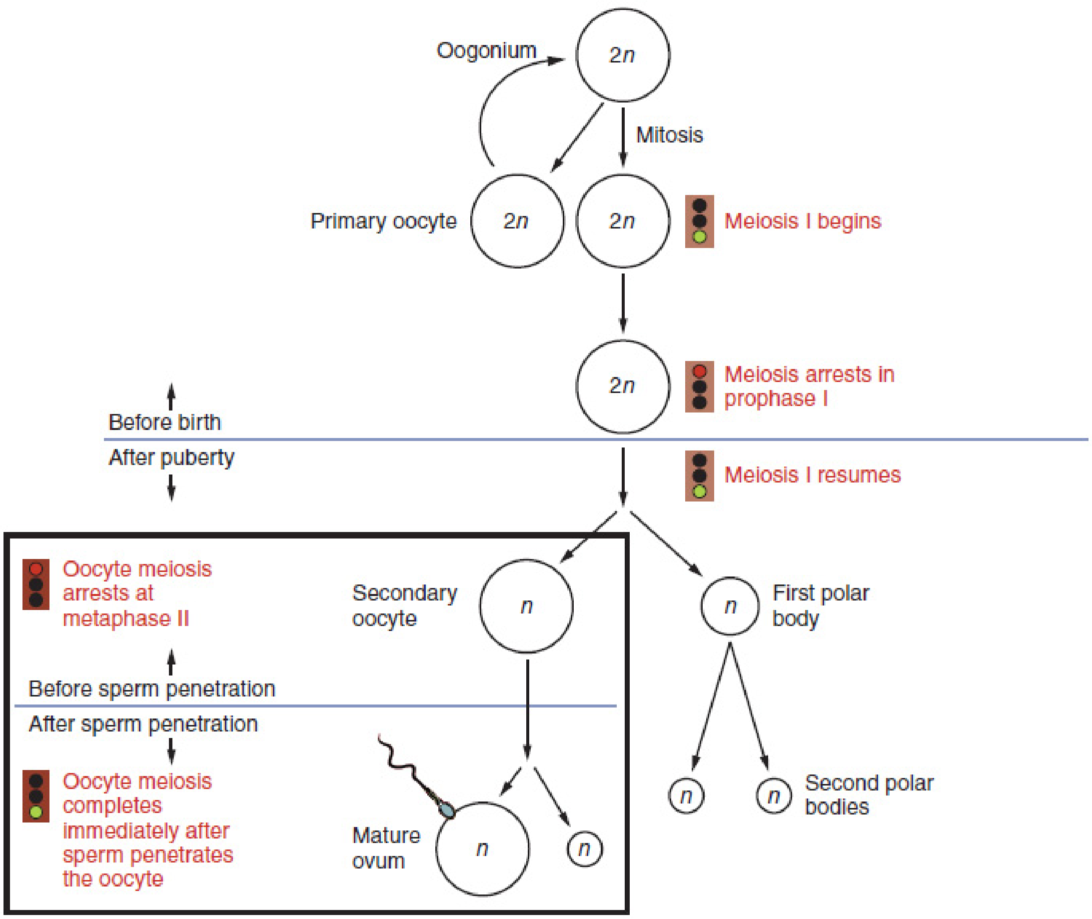
Oogenesis

Gametogenesis (making of gametes or sex cells) in females is called **oogenesis**. The process begins with the ovarian stem cells, or **oogonia** ([link]). Oogonia are formed during fetal development, and divide via mitosis, much like spermatogonia in the testis. Unlike spermatogonia, however, oogonia form primary **oocytes** in the fetal ovary **prior** to birth. These primary oocytes are then arrested in this stage of meiosis I, only to resume it years later, beginning at puberty and continuing until the woman

is near menopause (the cessation of a woman's reproductive functions). The number of primary oocytes present in the ovaries declines from one to two million in an infant, to approximately 400,000 at puberty, to zero by the end of menopause.

The start of **ovulation**—the release of an oocyte from the ovary—marks the transition from puberty into reproductive maturity for women. From then on, throughout a woman's reproductive years, ovulation occurs approximately once every 28 days. Just prior to ovulation, a surge of luteinizing hormone (LH) triggers the resumption of meiosis in a **primary oocyte**. This causes a primary oocyte to change into a **secondary oocyte**. However, as you can see in [link], this cell division does not result in two identical cells. Instead, the cytoplasm is divided unequally, and one daughter cell is much larger than the other. This larger cell, the secondary oocyte, eventually leaves the ovary during ovulation. The smaller cell, called the first **polar body**, may or may not complete meiosis and produce second polar bodies; in either case, it eventually disintegrates. Therefore, even though oogenesis produces up to four cells, only one survives.

Oogenesis



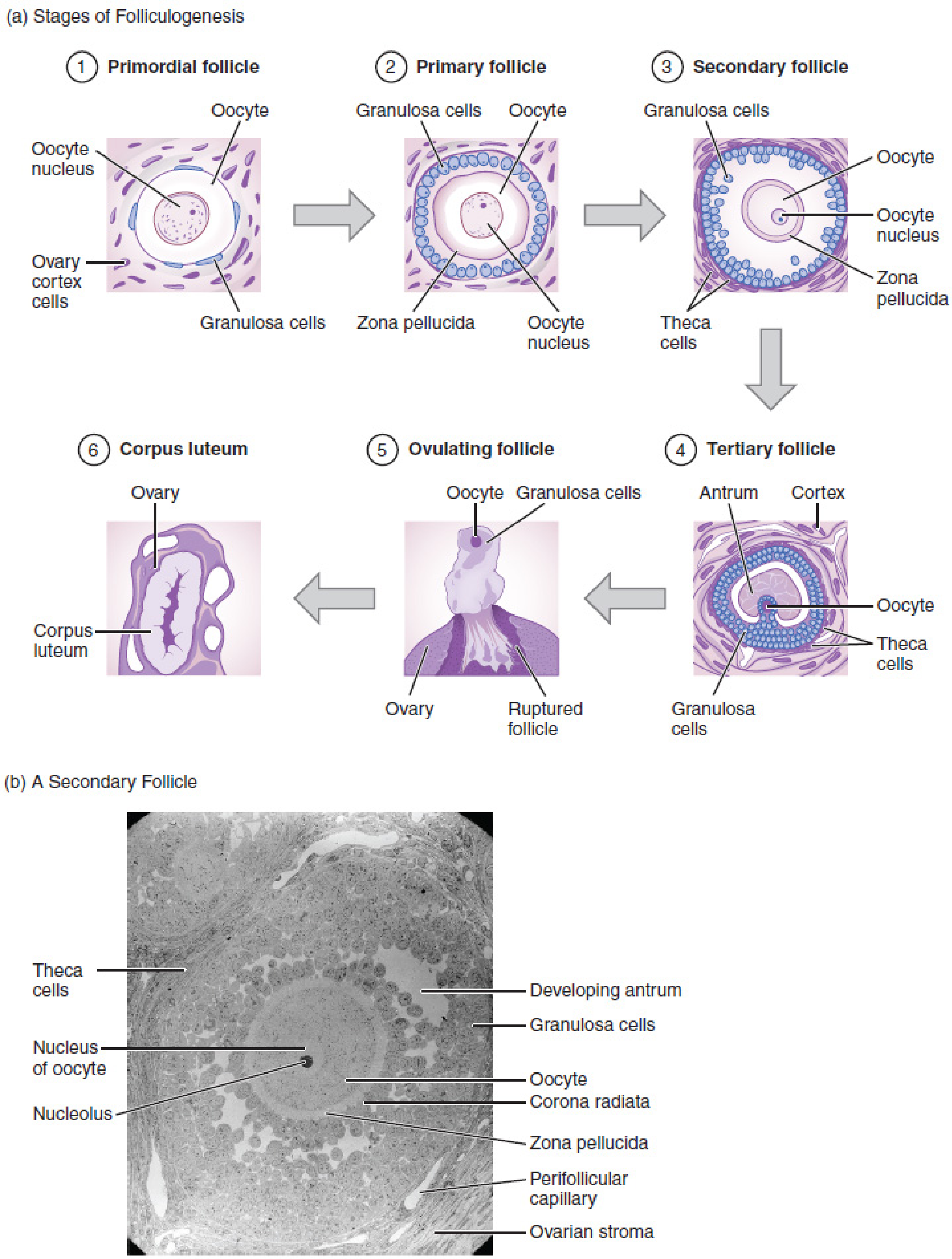
The unequal cell division of oogenesis produces one to three polar bodies that later degrade, as well as a single haploid ovum, which is produced only if there is penetration of the secondary oocyte by a sperm cell.

How does the **diploid** (2 copies of chromosomes) secondary oocyte become an **ovum**—the **haploid** (1 copy of chromosomes) female gamete? Meiosis of a secondary oocyte is completed only if a sperm succeeds in penetrating the egg. Cell division resumes, producing one haploid ovum that, at the instant of fertilization by a sperm, becomes the first diploid cell of the new offspring (a zygote).

Folliculogenesis

Again, **ovarian follicles** are oocytes and their supporting cells. They grow and develop which typically leads to ovulation of one follicle approximately every 28 days. As you'll see next, follicles progress from primordial, to primary, to secondary and tertiary stages prior to ovulation—with the oocyte inside the follicle remaining as a primary oocyte until right before ovulation. Follicles begins in a resting state. These small **primordial follicles** are present in newborn females and are the prevailing follicle type in the adult ovary ([link]).

After puberty, a few primordial follicles will start to develop each day. These developing follicles are called **primary follicles**. Changes to the cells of the folliclesPrimary follicles start with a single layer of granulosa cells, but the granulosa cells then become active and transition from a flat or squamous shape to a rounded, cuboidal shape as they increase in size and proliferate. As the granulosa cells divide, the follicles—now called **secondary follicles** (see [link])—increase in diameter, adding a new outer layer of connective tissue, blood vessels, and **theca cells**—cells that work with the granulosa cells to produce estrogens.
Folliculogenesis



(a) The maturation of a follicle is shown in a clockwise direction proceeding from the primordial follicles. FSH stimulates the growth of a tertiary follicle, and LH stimulates the production of estrogen by granulosa and theca cells. Once the follicle is mature, it ruptures and releases the oocyte. Cells

remaining in the follicle then develop into the corpus luteum. (b) In this electron micrograph of a secondary follicle, the oocyte, theca cells (thecae folliculi), and developing antrum are clearly visible. EM × 1100. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

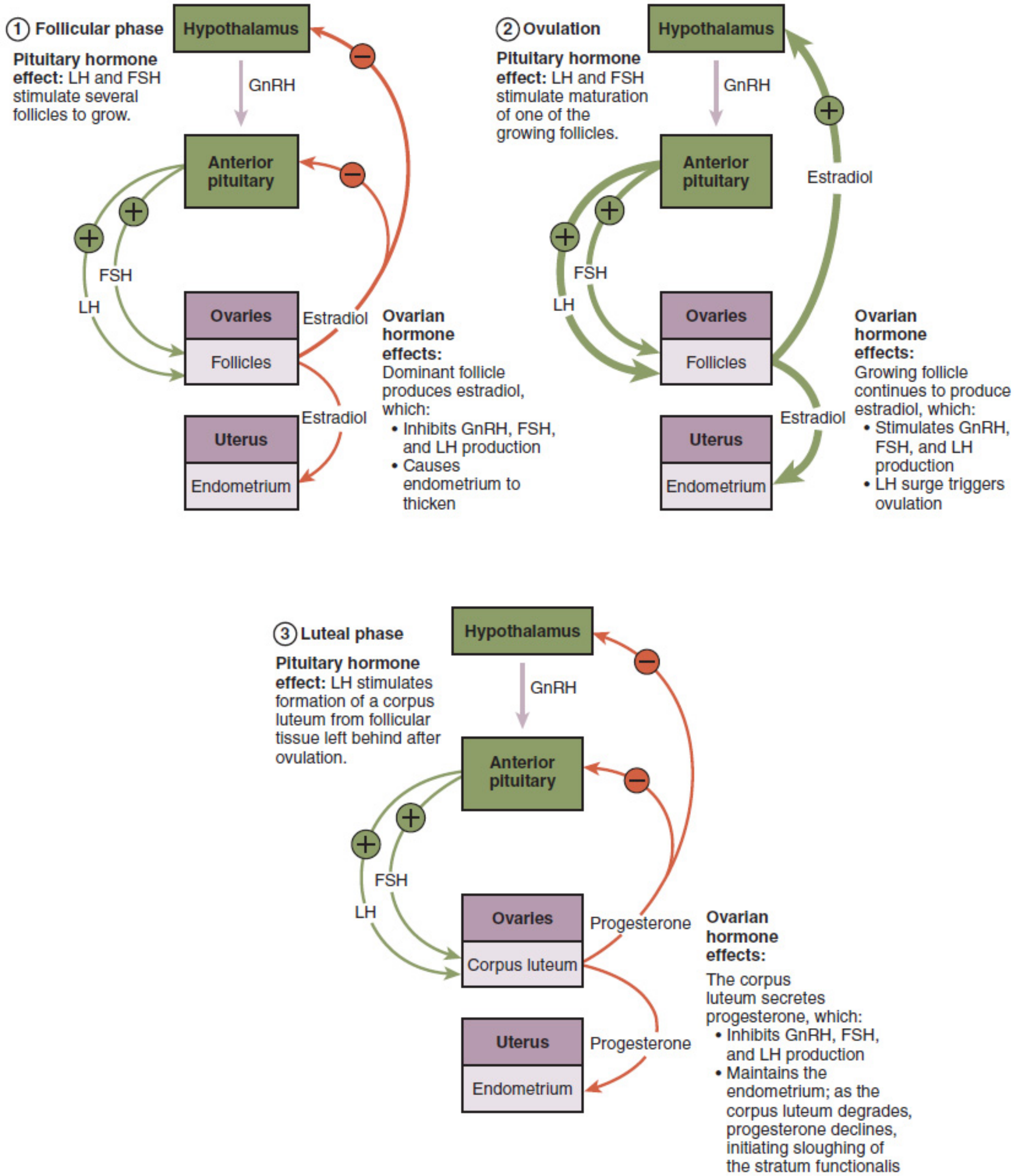
Hormonal Control of the Ovarian Cycle-SECOND PORTION OF READING STARTS HERE

The process of development ends with ovulation of a secondary oocyte. The process occurs over a course of approximately 28 days. These changes are regulated by many of the same hormones that regulate the male reproductive system, including GnRH, LH, and FSH.

As in men, the **hypothalamus produces GnRH** (Gonadotropin Releasing Hormone), a hormone that signals the **anterior pituitary gland** to produce the gonadotropins **FSH (follicle stimulating hormone)** and **LH (luteinizing hormone)**([link]). These hormones leave the pituitary and travel through the bloodstream to the ovaries, where they bind to receptors on the cells of the follicles. FSH stimulates the follicles to grow (hence its name of follicle-stimulating hormone). The release of LH also stimulates cells of the follicles to produce the sex steroid hormone estradiol, a type of **estrogen**. This phase of the ovarian cycle, when the follicles are growing and secreting estrogen, is known as the **follicular phase**.

The more cells a follicle has (that is, the larger and more developed it is), the more estrogen it will produce in response to LH stimulation. As a result of these large follicles producing large amounts of estrogen, blood levels of estrogen concentrations increase. The high concentrations of estrogen will stimulate the hypothalamus and pituitary to reduce the production of GnRH, LH, and FSH. Because the large follicles require FSH to grow and survive at this point, this decline in FSH leads most of them to die. Typically, only one follicle will survive this reduction in FSH and is known as the **dominant follicle**. This follicle will be the one that releases an **oocyte**(egg).

Hormonal Regulation of Ovulation



The hypothalamus and pituitary gland regulate the ovarian cycle and ovulation. GnRH activates the anterior pituitary to produce LH and FSH, which stimulate the production of estrogen and progesterone by the ovaries.

When only the one dominant follicle remains in the ovary, it begins to greatly increase **estrogen** production. It produces so much estrogen that the normal negative feedback doesn't occur. Instead, these extremely high concentrations of estrogen in the blood triggers the anterior pituitary to begin secreting large amounts of LH and FSH into the bloodstream (see [link]).

It is this large burst of LH that leads to ovulation of the dominant follicle. The LH surge induces many changes in the dominant follicle, including stimulating the return to cell division. As noted earlier, the polar body that results from unequal cell division simply degrades. The dominant follicle bulges out from the surface of the ovary. This combined with pressure from the large, fluid-filled follicle, results in the expulsion of the oocyte into the peritoneal cavity. This release is **ovulation**.

The surge of LH also stimulates a change in the follicle cells that remain in the follicle after the oocyte has been ovulated. This change is called **luteinization** (recall that the full name of LH is luteinizing hormone), and it transforms the collapsed follicle into a new endocrine structure called the **corpus luteum**, a term meaning “yellowish body” (see [link]). Instead of estrogen, the corpus luteum begins to produce large amounts of the sex steroid hormone **progesterone**, a hormone that is critical for the **establishment and maintenance of pregnancy**. The increase in progesterone signals the brain to keep GnRH, LH, and FSH secretions low, so no new dominant follicles develop at this time.

If pregnancy does not occur within 10 to 12 days, the corpus luteum will stop secreting progesterone and degrade into the **corpus albicans**, a nonfunctional “whitish body” that will disintegrate over a period of several months. During this time progesterone production is greatly reduced and FSH and LH are once again stimulated producing new growino grow and secrete estrogen.

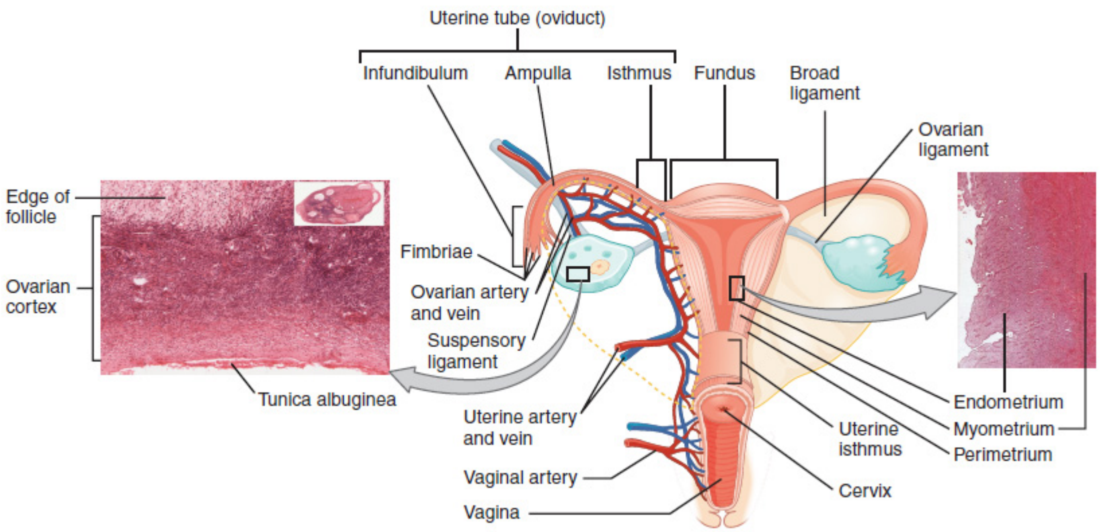
The Uterine Tubes

The **uterine tubes** (also called fallopian tubes or oviducts) serve as the pathway of the oocyte from the ovary to the uterus ([link]). Each of the two

uterine tubes is close to, but not directly connected to, the ovary and divided into sections. The **isthmus** is the narrow medial end of each uterine tube that is connected to the uterus. The wide distal **infundibulum** flares out with slender, finger-like projections called **fimbriae**. The middle region of the tube, called the **ampulla**, is where fertilization often occurs. The uterine tubes also have three layers: an outer serosa, a middle smooth muscle layer, and an inner mucosal layer. In addition to its mucus-secreting cells, the inner mucosa contains ciliated cells that beat in the direction of the uterus, producing a current that will be critical to move the oocyte.

Following ovulation, the uterine tubes receive the oocyte. Unlike sperm, oocytes lack flagella, and therefore cannot move on their own. So how do they travel into the uterine tube and toward the uterus? Around the time of ovulation, contractions occur in the smooth muscle along the length of the uterine tube. These contractions result in a coordinated movement that sweeps the egg toward the opening of the uterine tube. Current flowing toward the uterus is generated by coordinated beating of the **cilia** that line the outside and the length of the uterine tube. Once the egg is inside, the muscular contractions and beating cilia move the oocyte slowly toward the uterus. When fertilization does occur, sperm typically meet the egg while it is still moving through the uterine tube.

If the oocyte is successfully fertilized, the resulting zygote will begin to divide into two cells, then four, and so on, as it makes its way through the uterine tube and into the uterus. There, it will implant and continue to grow. If the egg is not fertilized, it will simply degrade—either in the uterine tube or in the uterus, where it may be shed with the next menstrual period.
Ovaries, Uterine Tubes, and Uterus



This anterior view shows the relationship of the ovaries, uterine tubes (oviducts), and uterus. Sperm enter through the vagina, and fertilization of an ovulated oocyte usually occurs in the distal uterine tube. From left to right, LM × 400, LM × 20. (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

The open-ended structure of the uterine tubes can have significant health consequences if bacteria or other contagions enter through the vagina and move through the uterus, into the tubes, and then into the pelvic cavity. Unlike the male reproductive system, this is not a "closed system". If an infection occurs, it could quickly become life-threatening. The **infection can easily move** from the open end of the uterine tubes into the pelvic cavity. The spread of an infection in this manner is of special concern when unskilled practitioners perform abortions in non-sterile conditions. Many STDs increase a woman’s risk for **pelvic inflammatory disease (PID)**, infection of the uterine tubes or other reproductive organs. Even when resolved, PID can leave scar tissue in the tubes, leading to infertility.

The Uterus and Cervix

The **uterus** is the muscular organ that nourishes and supports the growing embryo (see [link]). Its average size is approximately 5 cm wide by 7 cm long (approximately 2 in by 3 in) when a female is not pregnant. It has three sections. The portion of the uterus superior to the opening of the uterine tubes is called the **fundus**. The middle section of the uterus is called the **body of uterus**. The **cervix** is the narrow inferior portion of the uterus that projects into the vagina.

Several ligaments maintain the position of the reproductive organs in the abdominopelvic cavity. The ligaments of the female reproductive tract can be divided into three categories: **Broad ligament** which is a sheet of peritoneum, associated with both the uterus and ovaries. **Uterine ligaments** are ligaments that support the uterus. The third type, **ovarian ligaments** support the ovaries.

The wall of the uterus is made up of three layers. The most superficial layer is the serous membrane, or **perimetrium**, which consists of epithelial tissue that covers the exterior portion of the uterus. The thick middle layer, or **myometrium**, is a layer of smooth muscle responsible for uterine contractions during childbirth and menstruation. The innermost layer of the uterus is called the **endometrium**. It is the endometrium that grows and thickens in response to increased levels of estrogen and progesterone. It is the endometrium that sheds during menstruation. The endometrial tissue dies and blood, pieces of the endometrial tissue, and white blood cells are shed through the vagina during menstruation, or the **menses**. The first menses after puberty, called **menarche**, can occur either before or after the first ovulation.

The Menstrual Cycle THIRD PORTION OF READING STARTS HERE

The timing of the **menstrual cycle** starts with the first day of menses, referred to as day one of a woman’s period. Cycle length is determined by counting the days between the onset of bleeding in two cycles. Because the average length of a woman’s menstrual cycle is 28 days, this is the time period used to identify the timing of events in the cycle. However, the

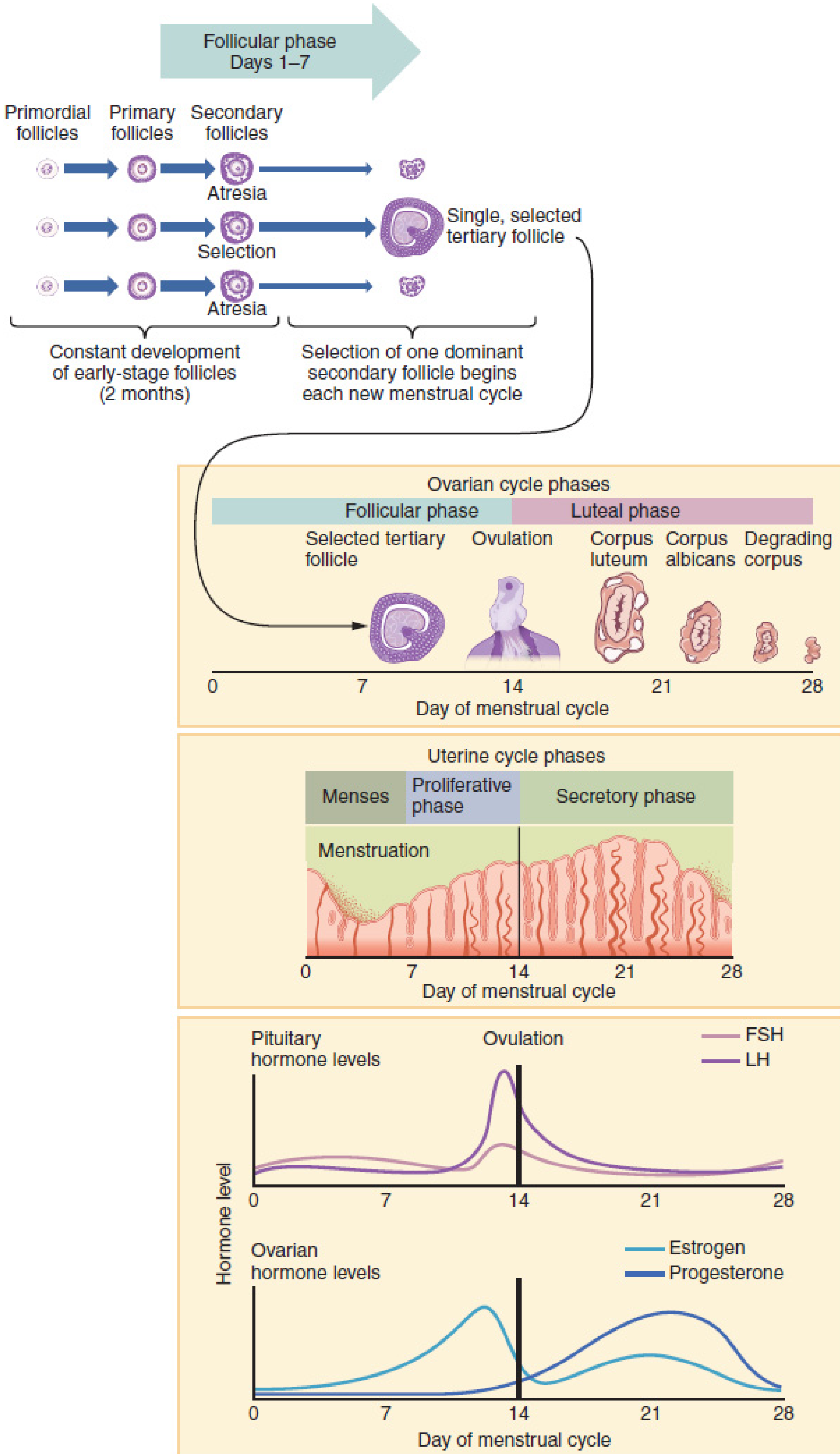
length of the menstrual cycle varies among women, and even in the same woman from one cycle to the next, typically from 21 to 32 days.

Hormones produced by reproductive system “drive” the phases of the ovarian cycle, they also control the three distinct phases of the menstrual cycle. These are the menses phase, the proliferative phase, and the secretory phase.

Menses Phase

The **menses phase** of the menstrual cycle is the phase during which the lining is shed; that is, the days that the woman menstruates. Although it averages approximately five days, the menses phase can last from 2 to 7 days, or longer. As shown in [link], the menses phase occurs during the early days of the ovarian cycle, when progesterone, FSH, and LH levels are low. The **decline in progesterone** triggers the shedding of the endometrium.

Hormone Levels in Ovarian and Menstrual Cycles



Follicular phase
Days 1–7
Primordial follicles
Primary follicles
Secondary follicles
Atresia
Single, selected tertiary follicle
Selection
Atresia
Constant development of early-stage follicles (2 months)
Selection of one dominant secondary follicle begins each new menstrual cycle
Ovarian cycle phases
Follicular phase
Luteal phase
Selected tertiary follicle
Ovulation
Corpus luteum
Corpus albicans
Degrading corpus
0
7
14
21
28
Day of menstrual cycle
Uterine cycle phases
Menses
Proliferative phase
Secretory phase
Menstruation
0
7
14
21
28
Day of menstrual cycle
Pituitary hormone levels
Ovulation
FSH
LH
0
7
14
21
28
Hormone level
Ovarian hormone levels
Estrogen
Progesterone
0
7
14
21
28
Day of menstrual cycle

The correlation of the hormone levels and their effects on the female reproductive system is shown in this timeline of the ovarian and menstrual cycles. The menstrual cycle begins at day one with the start of menses. Ovulation occurs around day 14 of a 28-day cycle, triggered by the LH surge.

Proliferative Phase

Once menstrual flow ceases, the endometrium begins to thicken again, marking the beginning of the **proliferative phase** of the menstrual cycle (see [link]). It occurs when the the ovaries begin to produce increased amounts of estrogen. These rising estrogen concentrations stimulate the endometrial lining to rebuild. Ovulation marks the end of the proliferative phase as well as the end of the follicular phase.

Secretory Phase

High estrogen levels increase the uterine tube contractions that facilitate the pick-up and transfer of the ovulated oocyte. High estrogen levels also slightly decrease the acidity of the vagina, making it more hospitable to sperm. In the ovary, the empty follicle forms the progesterone-producing corpus luteum, marking the beginning of the luteal phase of the ovarian cycle. In the uterus, progesterone from the **corpus luteum** begins the **secretory phase** of the menstrual cycle, in which the endometrial lining prepares for implantation (see [link]). Over the next 10 to 12 days, the **endometrial glands** secrete a fluid rich in glycogen. If fertilization has occurred, this fluid will nourish the ball of cells now developing from the zygote.

If no pregnancy occurs within approximately 10 to 12 days, the corpus luteum will degrade into the corpus albicans. Levels of both estrogen and progesterone will fall, and the endometrium will grow thinner. Prostaglandins will be secreted that cause constriction of the spiral arteries, reducing oxygen supply. The endometrial tissue will die, resulting in menses—or the first day of the next cycle.

Note:

Disorders of the… Feature

Female Reproductive System

Research over many years has confirmed that cervical cancer is most often caused by a sexually transmitted infection with **human papillomavirus (HPV)**. There are over 100 related viruses in the HPV family, and the characteristics of each strain determine the outcome of the infection. In all cases, the virus enters body cells and uses its own genetic material to take over the host cell's metabolic machinery and produce more virus particles.

HPV infections are common in both men and women. Indeed, a recent study determined that **42.5 percent of females had HPV at the time of testing**. These women ranged in age from 14 to 59 years and differed in race, ethnicity, and number of sexual partners. Of note, the prevalence of HPV infection was 53.8 percent among women aged 20 to 24 years, the age group with the highest infection rate.

Most HPV infections do not cause disease, but the disruption of normal cellular functions in the low-risk forms of HPV can cause the male or female human host to develop **genital warts**. Often, the body is able to clear an HPV infection by normal immune responses within 2 years. However, the more serious, high-risk infection by certain types of HPV can result in cancer of the cervix ([link]). Infection with either of the cancer-causing variants **HPV 16 or HPV 18** has been linked to more than 70 percent of all cervical cancer diagnoses. Although even these high-risk HPV strains can be cleared from the body over time, infections persist in some individuals. If this happens, the HPV infection can influence the cells of the cervix to develop precancerous changes.

Risk factors for cervical cancer include having unprotected sex; having multiple sexual partners; a first sexual experience at a younger age, when

the cells of the cervix are not fully mature; failure to receive the HPV vaccine; a compromised immune system; and smoking. The risk of developing cervical cancer is doubled with cigarette smoking.

The prevalence of cervical cancer in the United States is very low because of regular screening exams called **pap smears**. Pap smears sample cells of the cervix, allowing the detection of abnormal cells. If pre-cancerous cells are detected, there are several highly effective techniques that are currently in use to remove them before they pose a danger. However, women in developing countries often do not have access to regular pap smears. As a result, these women account for as many as 80 percent of the cases of cervical cancer worldwide.

In 2006, the first vaccine against the high-risk types of HPV was approved. There are now two HPV vaccines available: Gardasil® and Cervarix®. Whereas these vaccines were initially only targeted for women, because HPV is sexually transmitted, both men and women require vaccination for this approach to achieve its maximum efficacy. A recent study suggests that the HPV vaccine has cut the rates of HPV infection by the four targeted strains at least in half. Unfortunately, the high cost of manufacturing the vaccine is currently limiting access to many women worldwide.

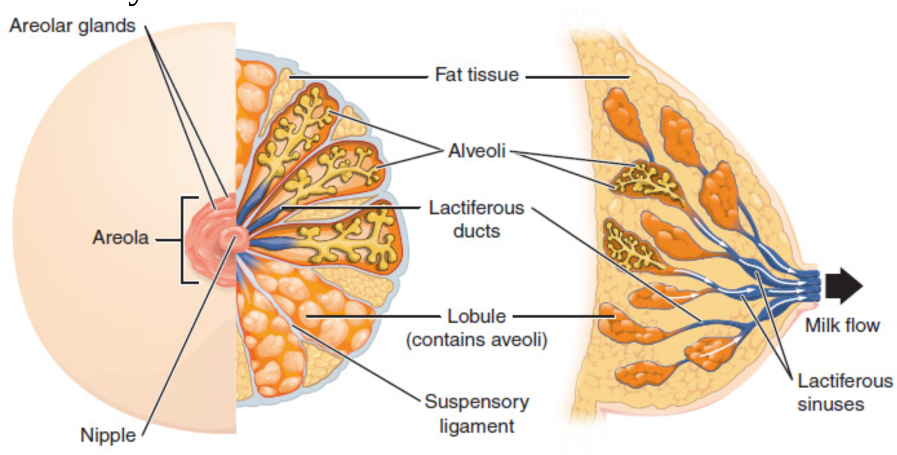
The Breasts

Whereas the breasts are located far from the other female reproductive organs, they are considered **accessory organs** of the female reproductive system. The function of the breasts is to supply milk to an infant in a process called **lactation**. The external features of the breast include a nipple surrounded by a pigmented **areola** ([link]), whose coloration may deepen during pregnancy. The areola is typically circular and can vary in size.

Breast milk is produced by the **mammary glands**, which are modified sweat glands (Does that make mild modified sweat?). The milk itself exits the breast through the nipple via 15 to 20 **lactiferous ducts** that open on the surface of the nipple. These lactiferous ducts each extend to a **lactiferous sinus**. Groups of cells in clusters called **alveoli** (see [link]) produce the

milk. Once milk is made in the alveoli, cells push the milk to the lactiferous sinuses. From here, the baby can draw milk through the ducts by suckling. The lobes themselves are surrounded by fat tissue, which determines the size of the breast; breast size differs between individuals and does not affect the amount of milk produced.

Anatomy of the Breast



During lactation, milk moves from the alveoli through the lactiferous ducts to the nipple.

Hormonal Birth Control

Birth control pills take advantage of the **hormonal feedback system** that regulates the ovarian and menstrual cycles to stop ovulation and prevent pregnancy. They work by providing a constant level of both estrogen and progesterone, which communicate the hypothalamus and pituitary, This prevents the release of FSH and LH. Without FSH, the follicles do not mature, and without the LH surge, ovulation does not occur.

Some birth control pills contain 21 active pills containing hormones, and 7 inactive pills (placebos). The decline in hormones during the week that the woman takes the placebo pills triggers menses, although it is typically lighter than a normal menstrual flow. Newer types of birth control pills have been developed that deliver low-dose estrogens and progesterone for the entire cycle (these are meant to be taken 365 days a year), and menses never

occurs. While some women prefer to have the proof of a lack of pregnancy that a monthly period provides, menstruation every 28 days is not required for health reasons, and there are no reported adverse effects of not having a menstrual period in an otherwise healthy individual.

Note:

Aging and the… Feature

Female Reproductive System

Female fertility (the ability to conceive) peaks when women are in their twenties, and is slowly reduced until a women reaches 35 years of age. After that time, fertility declines more rapidly, until it ends completely at the end of menopause. **Menopause** is the stopping of the menstrual cycle that occurs as a result of the loss of ovarian follicles and the hormones that they produce. A woman is considered to have completed menopause if she has not menstruated in a full year. After that point, she is considered postmenopausal. The average age for this change is consistent worldwide at between 50 and 52 years of age, but it can normally occur in a woman's forties, or later in her fifties. Poor health, including smoking, can lead to earlier loss of fertility and earlier menopause. It is primarily the **lack of estrogens** that leads to the symptoms of menopause. As estrogen levels change, other symptoms that occur are hot flashes and night sweats, trouble sleeping, vaginal dryness, mood swings, difficulty focusing, and thinning of hair on the head along with the growth of more hair on the face. Depending on the individual, these symptoms can be entirely absent, moderate, or severe.

After menopause, lower amounts of estrogens can lead to other changes. Cardiovascular disease becomes as prevalent in women as in men, possibly because estrogens reduce the amount of cholesterol in the blood vessels. When estrogen is lacking, many women find that they suddenly have problems with high cholesterol and the cardiovascular issues that accompany it. Osteoporosis is another problem because bone density decreases rapidly in the first years after menopause. The reduction in bone density leads to a higher incidence of fractures.

Chapter Review

The external female genitalia are collectively called the vulva. The vagina is the pathway into and out of the uterus. The man’s penis is inserted into the vagina to deliver sperm, and the baby exits the uterus through the vagina during childbirth.

The ovaries produce oocytes, the female gametes, in a process called oogenesis. As with spermatogenesis, meiosis produces the haploid gamete (in this case, an ovum); however, it is completed only in an oocyte that has been penetrated by a sperm. In the ovary, an oocyte surrounded by supporting cells is called a follicle. In folliculogenesis, primordial follicles develop into primary, secondary, and tertiary follicles. Early tertiary follicles with their fluid-filled antrum will be stimulated by an increase in FSH, a gonadotropin produced by the anterior pituitary, to grow in the 28-day ovarian cycle. Supporting granulosa and theca cells in the growing follicles produce estrogens, until the level of estrogen in the bloodstream is high enough that it triggers negative feedback at the hypothalamus and pituitary. This results in a reduction of FSH and LH, and most tertiary follicles in the ovary undergo atresia (they die). One follicle, usually the one with the most FSH receptors, survives this period and is now called the dominant follicle. The dominant follicle produces more estrogen, triggering positive feedback and the LH surge that will induce ovulation. Following ovulation, the granulosa cells of the empty follicle luteinize and transform into the progesterone-producing corpus luteum. The ovulated oocyte with its surrounding granulosa cells is picked up by the infundibulum of the uterine tube, and beating cilia help to transport it through the tube toward the uterus. Fertilization occurs within the uterine tube, and the final stage of meiosis is completed.

The uterus has three regions: the fundus, the body, and the cervix. It has three layers: the outer perimetrium, the muscular myometrium, and the inner endometrium. The endometrium responds to estrogen released by the follicles during the menstrual cycle and grows thicker with an increase in blood vessels in preparation for pregnancy. If the egg is not fertilized, no signal is sent to extend the life of the corpus luteum, and it degrades, stopping progesterone production. This decline in progesterone results in

the sloughing of the inner portion of the endometrium in a process called menses, or menstruation.

The breasts are accessory sexual organs that are utilized after the birth of a child to produce milk in a process called lactation. Birth control pills provide constant levels of estrogen and progesterone to negatively feed back on the hypothalamus and pituitary, and suppress the release of FSH and LH, which inhibits ovulation and prevents pregnancy.

Glossary

alveoli
: (of the breast) milk-secreting cells in the mammary gland

ampulla
: (of the uterine tube) middle portion of the uterine tube in which fertilization often occurs

antrum
: fluid-filled chamber that characterizes a mature tertiary (antral) follicle

areola
: highly pigmented, circular area surrounding the raised nipple and containing areolar glands that secrete fluid important for lubrication during suckling

Bartholin’s glands
: (also, greater vestibular glands) glands that produce a thick mucus that maintains moisture in the vulva area; also referred to as the greater vestibular glands

body of uterus
: middle section of the uterus

broad ligament
: wide ligament that supports the uterus by attaching laterally to both sides of the uterus and pelvic wall

cervix

elongate inferior end of the uterus where it connects to the vagina

clitoris

(also, glans clitoris) nerve-rich area of the vulva that contributes to sexual sensation during intercourse

corpus albicans

nonfunctional structure remaining in the ovarian stroma following structural and functional regression of the corpus luteum

corpus luteum

transformed follicle after ovulation that secretes progesterone

endometrium

inner lining of the uterus, part of which builds up during the secretory phase of the menstrual cycle and then sheds with menses

fimbriae

fingerlike projections on the distal uterine tubes

follicle

ovarian structure of one oocyte and surrounding granulosa (and later theca) cells

folliculogenesis

development of ovarian follicles from primordial to tertiary under the stimulation of gonadotropins

fundus

(of the uterus) domed portion of the uterus that is superior to the uterine tubes

granulosa cells

supportive cells in the ovarian follicle that produce estrogen

hymen

membrane that covers part of the opening of the vagina

infundibulum
(of the uterine tube) wide, distal portion of the uterine tube terminating in fimbriae

isthmus
narrow, medial portion of the uterine tube that joins the uterus

labia majora
hair-covered folds of skin located behind the mons pubis

labia minora
thin, pigmented, hairless flaps of skin located medial and deep to the labia majora

lactiferous ducts
ducts that connect the mammary glands to the nipple and allow for the transport of milk

lactiferous sinus
area of milk collection between alveoli and lactiferous duct

mammary glands
glands inside the breast that secrete milk

menarche
first menstruation in a pubertal female

menses
shedding of the inner portion of the endometrium out though the vagina; also referred to as menstruation

menses phase
phase of the menstrual cycle in which the endometrial lining is shed

menstrual cycle
approximately 28-day cycle of changes in the uterus consisting of a menses phase, a proliferative phase, and a secretory phase

mons pubis

mound of fatty tissue located at the front of the vulva

myometrium
: smooth muscle layer of uterus that allows for uterine contractions during labor and expulsion of menstrual blood

oocyte
: cell that results from the division of the oogonium and undergoes meiosis I at the LH surge and meiosis II at fertilization to become a haploid ovum

oogenesis
: process by which oogonia divide by mitosis to primary oocytes, which undergo meiosis to produce the secondary oocyte and, upon fertilization, the ovum

oogonia
: ovarian stem cells that undergo mitosis during female fetal development to form primary oocytes

ovarian cycle
: approximately 28-day cycle of changes in the ovary consisting of a follicular phase and a luteal phase

ovaries
: female gonads that produce oocytes and sex steroid hormones (notably estrogen and progesterone)

ovulation
: release of a secondary oocyte and associated granulosa cells from an ovary

ovum
: haploid female gamete resulting from completion of meiosis II at fertilization

perimetrium
: outer epithelial layer of uterine wall

polar body
: smaller cell produced during the process of meiosis in oogenesis

primary follicles
: ovarian follicles with a primary oocyte and one layer of cuboidal granulosa cells

primordial follicles
: least developed ovarian follicles that consist of a single oocyte and a single layer of flat (squamous) granulosa cells

proliferative phase
: phase of the menstrual cycle in which the endometrium proliferates

rugae
: (of the vagina) folds of skin in the vagina that allow it to stretch during intercourse and childbirth

secondary follicles
: ovarian follicles with a primary oocyte and multiple layers of granulosa cells

secretory phase
: phase of the menstrual cycle in which the endometrium secretes a nutrient-rich fluid in preparation for implantation of an embryo

suspensory ligaments
: bands of connective tissue that suspend the breast onto the chest wall by attachment to the overlying dermis

tertiary follicles
: (also, antral follicles) ovarian follicles with a primary or secondary oocyte, multiple layers of granulosa cells, and a fully formed antrum

theca cells
: estrogen-producing cells in a maturing ovarian follicle

uterine tubes

(also, fallopian tubes or oviducts) ducts that facilitate transport of an ovulated oocyte to the uterus

uterus
: muscular hollow organ in which a fertilized egg develops into a fetus

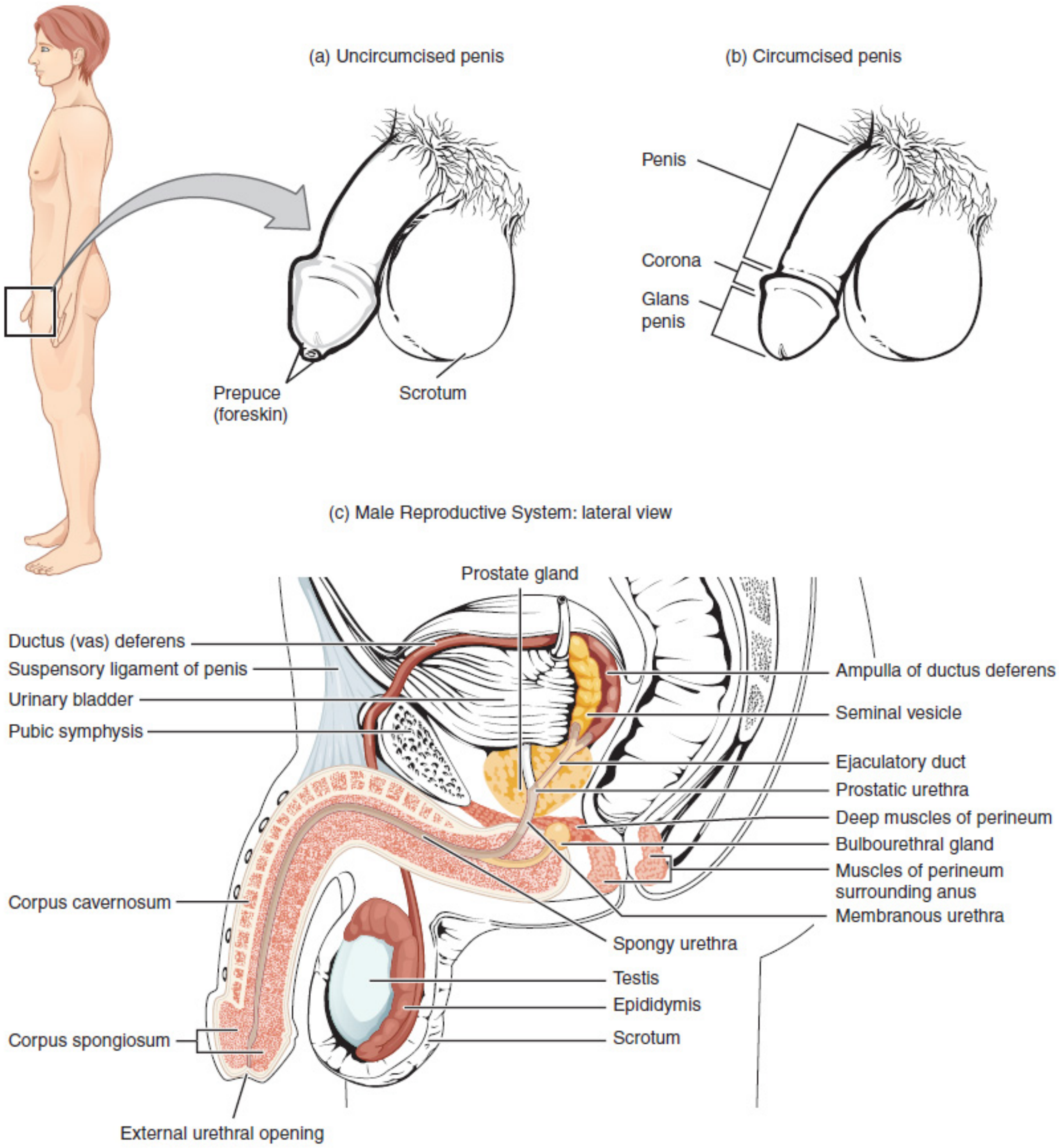
vagina
: tunnel-like organ that provides access to the uterus for the insertion of semen and from the uterus for the birth of a baby

vulva
: external female genitalia

Module 3 Anatomy and Physiology of the Male Reproductive System
By the end of this section, you will be able to:

- Describe the structure and function of the organs of the male reproductive system
- Describe the structure and function of the sperm cell
- Explain the events during spermatogenesis that produce haploid sperm from diploid cells
- Identify the importance of testosterone in male reproductive function

Unique for its role in human reproduction, a **gamete** is a specialized sex cell carrying 23 chromosomes—one half the number in body cells. At fertilization, the chromosomes in one male gamete, called a **sperm** (or spermatozoon), combine with the chromosomes in one female gamete, called an **oocyte**. The **function** of the male reproductive system ([link]) is to produce sperm and transfer them to the female reproductive tract. The paired testes are a crucial component in this process, as they produce both sperm and **androgens**, the hormones that support male reproductive physiology. In humans, the most important male androgen is testosterone. Several accessory organs and ducts aid the process of sperm maturation and transport the sperm and other seminal components to the penis, which delivers sperm to the female reproductive tract. In this section, we examine each of these different structures, and discuss the process of sperm production and transport.
Male Reproductive System



The structures of the male reproductive system include the testes, the epididymides, the penis, and the ducts and glands that produce and carry semen. Sperm exit the scrotum through the ductus deferens, which is bundled in the spermatic cord. The seminal vesicles and prostate gland add fluids to the sperm to create semen.

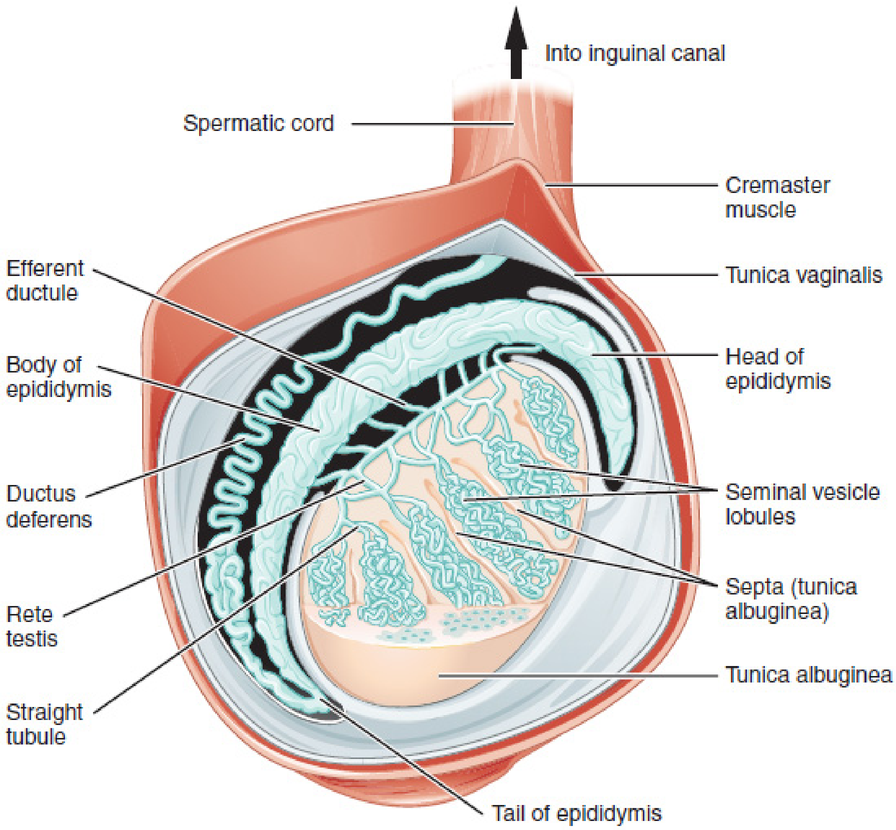
Scrotum

The testes are located in a skin-covered, highly pigmented, muscular sack called the **scrotum** that extends from the body behind the penis (see [link]). This location is important in sperm production, which occurs within the testes, and proceeds more efficiently when the testes are kept **2 to 4°C below core body temperature**. The **dartos muscle** and **cremaster muscles** make up the muscle layers of the scrotum. These muscles also form the scrotal septum, a wall that divides the scrotum into two compartments, each housing one testis. The dartos and cremaster muscles can elevate the testes in cold weather (or water), moving the testes closer to the body to retain heat. Alternatively, as the environmental temperature increases, the scrotum relaxes, moving the testes farther from the body.

Testes

The **testes** (singular = testis) are the male **gonads**—that is, the male reproductive organs. They produce both sperm and androgens, such as testosterone, and are active throughout the reproductive lifespan of the male. Paired ovals, the testes are housed within the scrotum (see [link]).Within the testis are **septa** (small compartments) that divide the testis into 300 to 400 structures called lobules. Within the lobules, sperm develop in structures called **seminiferous tubules**. A male fetus the testes develop within the abdomen. During the seventh month of development each testis moves through the abdominal musculature to descend into the scrotal cavity. This is called the “descent of the testis.” **Cryptorchidism** is the clinical term used when one or both of the testes fail to descend into the scrotum prior to birth.

Anatomy of the Testis



This sagittal view shows the seminiferous tubules, the site of sperm production. Formed sperm are transferred to the epididymis, where they mature. They leave the epididymis during an ejaculation via the ductus deferens.

The tightly coiled **seminiferous tubules** form the bulk of each testis. They are where sperm are formed and released into the duct system of the testis. Specifically, from the seminiferous tubules, sperm move into the **straight tubules** (or tubuli recti), and from there into a fine meshwork of tubules called the **rete testes**. Sperm leave the rete testes, and the testis itself, through the 15 to 20 **efferent ductules** of the testes.

Sertoli Cells

Surrounding all stages of the developing sperm cells are elongate, branching **Sertoli cells**. Sertoli cells are a type of supporting cell. Sertoli cells secrete signaling molecules that promote sperm production.

Germ Cells

The least mature cells, the **spermatogonia** (singular = spermatogonium), line the inside the tubule. Spermatogonia are the stem cells of the testis, which means that they are still able to differentiate into a variety of different cell types throughout adulthood. Spermatogonia divide to produce primary and secondary **spermatocytes**, then **spermatids**, which finally produce formed sperm. The process that begins with spermatogonia and concludes with the production of sperm is called **spermatogenesis**.

Spermatogenesis

The process of spermatogenesis begins at puberty, after which time sperm are produced constantly throughout a man’s life. One production cycle, from spermatogonia through formed sperm, takes approximately 64 days. **Sperm counts**—the total number of sperm a man produces—slowly decline after age 35.

The process of spermatogenesis begins with mitosis of the diploid spermatogonia ([link]). However, mature gametes are haploid (1*n*), containing 23 chromosomes—meaning that the spermatogonia must undergo a second cellular division through the process of **meiosis**.

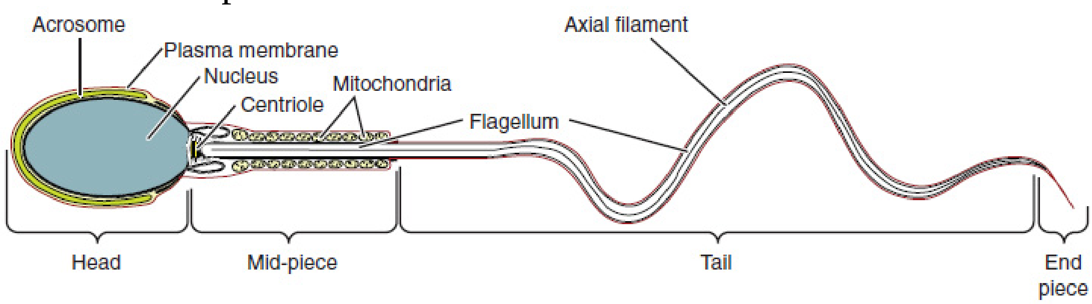
Start Module 3B

Start second reading here**************************.**

Structure of Formed Sperm

Sperm are smaller than most cells in the body; in fact, the volume of a sperm cell is 85,000 times less than that of the female gamete. Approximately 100 to 300 million sperm are produced each day, whereas women typically ovulate only one oocyte per month. The structure of sperm cells speaks to their function. Sperm have a distinctive **head, mid-piece, and tail region** ([link]). The head of the sperm contains a nucleus with very little cytoplasm. A structure called the **acrosome** covers most of the head of the sperm cell as a "cap" that is filled with enzymes important for preparing sperm to participate in fertilization. Tightly packed mitochondria fill the mid-piece of the sperm. ATP produced by these mitochondria will power the **flagellum**, which extends from the neck and the mid-piece through the tail of the sperm, enabling it to move the entire sperm cell.

Structure of Sperm



Sperm cells are divided into a head, containing DNA; a mid-piece, containing mitochondria; and a tail, providing motility. The acrosome is oval and somewhat flattened.

Sperm Transport

To fertilize an egg, sperm must be moved from the seminiferous tubules in the testes, through the epididymis, and—later during ejaculation—along the length of the penis and out into the female reproductive tract.

Role of the Epididymis

From the seminiferous tubules, the sperm are moved to the **epididymis**, a coiled tube attached to the testis where newly formed sperm continue to mature (see [link]). It takes an average of 12 days for sperm to move through the coils of the epididymis. As they move along the length of the epididymis, the sperm further mature and acquire the ability to move under their own power. Once inside the female reproductive tract, they will use this ability to move independently toward the unfertilized egg. The mature sperm are then stored in epididymis until ejaculation occurs.

Duct System

During ejaculation, sperm exit the tail of the epididymis and are pushed by smooth muscle contraction to the **ductus deferens** (also called the vas deferens). The ductus deferens is a thick, muscular tube that is bundled together inside the scrotum with connective tissue, blood vessels, and nerves into a structure called the **spermatic cord**. From each epididymis, each ductus deferens extends into the abdominal cavity through the **inguinal canal** in the abdominal wall. From here, the ductus deferens continues to the pelvic cavity, ending behind the bladder where it end in a region called the **ampulla**. Sperm make up only 5 percent of the final volume of **semen**, the thick, milky fluid that the male ejaculates. The bulk of semen is produced by three critical accessory glands of the male reproductive system: the seminal vesicles, the prostate, and the bulbourethral glands.

Seminal Vesicles

As sperm pass through the ampulla of the ductus deferens at ejaculation, they mix with fluid from the associated **seminal vesicle** (see [link]). The paired seminal vesicles are glands that contribute approximately 60 percent of the semen volume. Seminal vesicle fluid contains large amounts of sugars, which are used by the sperm to generate ATP to allow movement through the female reproductive tract. The fluid, now containing both sperm and seminal vesicle secretions, next moves into the associated **ejaculatory**

duct, a short structure formed from the ampulla of the ductus deferens and the duct of the seminal vesicle. The paired ejaculatory ducts transport the seminal fluid into the next structure, the prostate gland.

Prostate Gland

As shown in [link], the centrally located **prostate gland** sitsat the base of the bladder surrounding the **prostatic urethra** (the portion of the urethra that runs within the prostate). About the size of a walnut, it excretes an alkaline, milky fluid to the passing seminal fluid—now called semen—that is critical to to thicken the semen following ejaculation. The temporary thickening of semen helps retain it within the female reproductive tract, providing time for sperm to pass farther into the female reproductive tract.

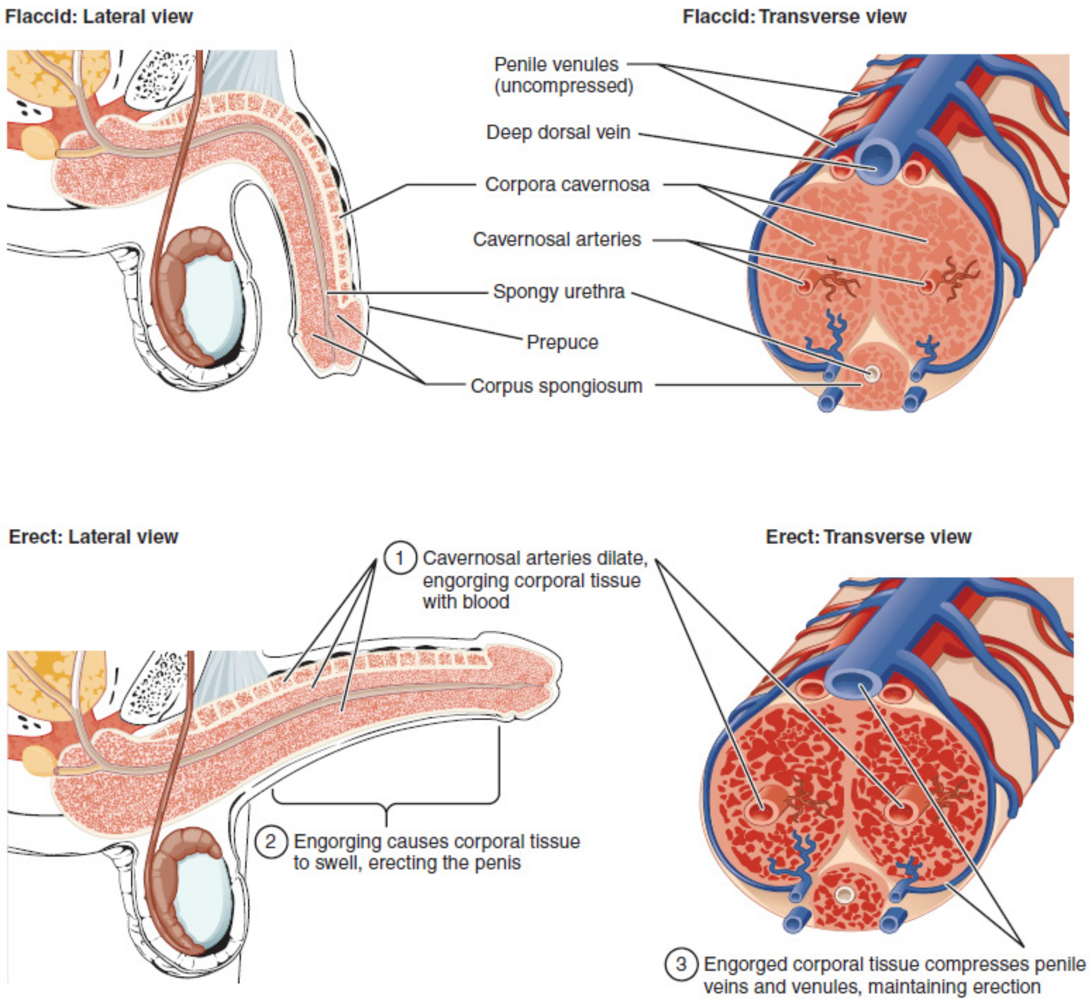
Bulbourethral Glands

The final addition to semen is made by two **bulbourethral glands** (or Cowper's glands) that release a thick, salty fluid that lubricates the end of the urethra and the vagina, and helps to clean urine residues from the **penile urethra**. The fluid from these accessory glands is released after the male becomes sexually aroused, and shortly before the release of the semen. It is therefore sometimes called pre-ejaculate. It is important to note that, in addition to the lubricating proteins, it is possible for bulbourethral fluid to pick up sperm already present in the urethra, and therefore it may be able to cause pregnancy.

The Penis

The **penis** is the male organ of **copulation** (sexual intercourse). When erect, the stiffness of the organ allows it to penetrate into the vagina and deposit semen into the female reproductive tract.

Cross-Sectional Anatomy of the Penis



Three columns of erectile tissue make up most of the volume of the penis.

The **shaft of the penis** surrounds the penile urethra ([link]). The shaft is composed of three column-like chambers of erectile tissue that span the length of the shaft. Each of the two larger lateral chambers is called a **corpus cavernosum**. Together, these make up the bulk of the penis. The **corpus spongiosum** surrounds the spongy, or penile, urethra. The end of the penis, called the **glans penis**, has a high concentration of nerve endings, resulting in very sensitive skin that influences the likelihood of ejaculation (see [link]). The skin from the shaft extends down over the glans and forms a collar called the **prepuce** (or foreskin). The foreskin also contains a dense

concentration of nerve endings, and both lubricate and protect the sensitive skin of the glans penis. A surgical procedure called **circumcision**, often performed for religious or social reasons, removes the prepuce, typically within days of birth.

Testosterone

Testosterone, an androgen, is a steroid hormone produced by **Leydig cells** or **interstitial cells**. In male embryos, testosterone is secreted by Leydig cells by the seventh week of development. This early release of testosterone results in the anatomical differentiation of the male sexual organs.

Functions of Testosterone

The continued **presence of testosterone** is necessary to keep the male reproductive system working properly. Maintaining these normal concentrations of testosterone promotes spermatogenesis, whereas low levels of testosterone can lead to infertility. In addition testosterone is also released into the blood circulation and plays an important role in muscle development, bone growth, the development of secondary sex characteristics, and maintaining libido (sex drive) in both males and females. In females, the ovaries secrete small amounts of testosterone.

Control of Testosterone

The regulation of testosterone concentrations throughout the body is critical for male reproductive function. The regulation of production of testosterone begins outside of the testes. The **hypothalamus** and the **pituitary gland** in the brain control testosterone production. The hypothalamus releases a hormone called **gonadotropin-releasing hormone (GnRH)**. Binding of GnRH to its receptors on the anterior pituitary gland stimulates release of **luteinizing hormone (LH)** and **follicle-stimulating hormone (FSH)**. These two hormones are critical for reproductive function in both men and

women. In men, FSH promotes spermatogenesis. LH binds to receptors on Leydig cells in the testes and influences the production of testosterone.

Section Summary

Gametes are the reproductive cells that combine to form offspring. Organs called gonads produce the gametes, along with the hormones that regulate human reproduction. The male gametes are called sperm. Spermatogenesis, the production of sperm, occurs within the seminiferous tubules that make up most of the testis. The scrotum is the muscular sac that holds the testes outside of the body cavity.

Spermatogenesis begins with mitotic division of spermatogonia (stem cells) to produce primary spermatocytes that undergo the two divisions of meiosis to become secondary spermatocytes, then the haploid spermatids. During spermiogenesis, spermatids are transformed into spermatozoa (formed sperm). Upon release from the seminiferous tubules, sperm are moved to the epididymis where they continue to mature. During ejaculation, sperm exit the epididymis through the ductus deferens, a duct in the spermatic cord that leaves the scrotum. The ampulla of the ductus deferens meets the seminal vesicle, a gland that contributes fructose and proteins, at the ejaculatory duct. The fluid continues through the prostatic urethra, where secretions from the prostate are added to form semen. These secretions help the sperm to travel through the urethra and into the female reproductive tract. Secretions from the bulbourethral glands protect sperm and cleanse and lubricate the penile (spongy) urethra.

The penis is the male organ of copulation. Columns of erectile tissue called the corpora cavernosa and corpus spongiosum fill with blood when sexual arousal activates vasodilatation in the blood vessels of the penis. Testosterone regulates and maintains the sex organs and sex drive, and induces the physical changes of puberty. Interplay between the testes and the endocrine system precisely control the production of testosterone with a negative feedback loop.

Glossary

blood–testis barrier

tight junctions between Sertoli cells that prevent bloodborne pathogens from gaining access to later stages of spermatogenesis and prevent the potential for an autoimmune reaction to haploid sperm

bulbourethral glands

(also, Cowper’s glands) glands that secrete a lubricating mucus that cleans and lubricates the urethra prior to and during ejaculation

corpus cavernosum

either of two columns of erectile tissue in the penis that fill with blood during an erection

corpus spongiosum

(plural = corpora cavernosa) column of erectile tissue in the penis that fills with blood during an erection and surrounds the penile urethra on the ventral portion of the penis

ductus deferens

(also, vas deferens) duct that transports sperm from the epididymis through the spermatic cord and into the ejaculatory duct; also referred as the vas deferens

ejaculatory duct

duct that connects the ampulla of the ductus deferens with the duct of the seminal vesicle at the prostatic urethra

epididymis

(plural = epididymides) coiled tubular structure in which sperm start to mature and are stored until ejaculation

gamete

haploid reproductive cell that contributes genetic material to form an offspring

glans penis

bulbous end of the penis that contains a large number of nerve endings

gonadotropin-releasing hormone (GnRH)
hormone released by the hypothalamus that regulates the production of follicle-stimulating hormone and luteinizing hormone from the pituitary gland

gonads
reproductive organs (testes in men and ovaries in women) that produce gametes and reproductive hormones

inguinal canal
opening in abdominal wall that connects the testes to the abdominal cavity

Leydig cells
cells between the seminiferous tubules of the testes that produce testosterone; a type of interstitial cell

penis
male organ of copulation

prepuce
(also, foreskin) flap of skin that forms a collar around, and thus protects and lubricates, the glans penis; also referred as the foreskin

prostate gland
doughnut-shaped gland at the base of the bladder surrounding the urethra and contributing fluid to semen during ejaculation

scrotum
external pouch of skin and muscle that houses the testes

semen
ejaculatory fluid composed of sperm and secretions from the seminal vesicles, prostate, and bulbourethral glands

seminal vesicle
gland that produces seminal fluid, which contributes to semen

seminiferous tubules
tube structures within the testes where spermatogenesis occurs

Sertoli cells
cells that support germ cells through the process of spermatogenesis; a type of sustentacular cell

sperm
(also, spermatozoon) male gamete

spermatic cord
bundle of nerves and blood vessels that supplies the testes; contains ductus deferens

spermatid
immature sperm cells produced by meiosis II of secondary spermatocytes

spermatocyte
cell that results from the division of spermatogonium and undergoes meiosis I and meiosis II to form spermatids

spermatogenesis
formation of new sperm, occurs in the seminiferous tubules of the testes

spermatogonia
(singular = spermatogonium) diploid precursor cells that become sperm

spermiogenesis
transformation of spermatids to spermatozoa during spermatogenesis

testes
(singular = testis) male gonads